MODIS Aerosol Algorithms. MOD04/MYD04 Status report: January 2004 to July 2005

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Summary:

The MODIS aerosol algorithm is successfully retrieving aerosol optical properties and providing useful products. We know this from the 28 published papers in 2004 alone that have used our products for real geophysical applications. We know this because the U.S. EPA chose our products over others to form the basis of a new decision support tool to aid operational air quality forecasting (Al-Saadi et al., 2005). Today, the operational air quality forecast that you read in the newspaper and hear on the radio, is in part based on our products.

The MODIS aerosol algorithms have been validated against AERONET on a global basis. Preliminary validation over land and ocean with a limited data set suggested that the aerosol optical thickness (AOT) was being retrieved within pre-launch specifications (Chu et al., 2002; Remer et al., 2002). The global validation was confirmed over both land and ocean using two years and over 8000 matched data points (Remer et al., 2005b). Further validation using three years of matched data points and separate Terra and Aqua data sets as well as different data collections, also proved the previous validation (Ichoku et al., 2005). However, regional eccentricities in the retrieval accuracy can be hidden in global validation plots. Regional validation studies from ACE-Asia (Chu et al., 2005) and CLAMS (Levy et al., 2005) provided new insight into the sensitivity of the ocean retrieval to the presence of dust and to subtle calibration issues over ocean, and to assumptions of surface properties and aerosol models over land.

In parallel to investigating the accuracy of the optical thickness retrievals, we have studied the accuracy of the ocean retrieval of aerosol find mode fraction (Kleidman et al., 2005). The results show a strong correlation to the values retrieved from the O'Neill inversion of AERONET sun data, although MODIS over predicts fine mode fraction of large particles.

We have spent some time investigating the possibility of cloud contamination in our products (Kaufman et al., 2005d). We acknowledge that approximately 0.015 in optical thickness or about 10 - 15% of the global aerosol optical thickness over the oceans is due to thin cirrus that cannot be masked. In addition, we have noticed an increase in MODIS over prediction of AERONET optical thickness as cloud fraction increases. However, this relationship cannot be simple cloud contamination in the MODIS product because we do not see a corresponding decrease of Angstrom Exponent that should accompany cloud contamination.

The MODIS products are being used for operational air quality forecasting, and for a variety of research applications by the entire scientific community. We, as a group, have also used the MODIS data for our own scientific research. We have quantified the amount of dust over the Atlantic (Kaufman et al., 2004c), identified the inverse relationship between smoke and clouds in the Amazon Basin (Koren et al., 2004), identified the positive correlation between aerosol amount and cloud coverage of shallow clouds over the Atlantic (Kaufman et al., 2005b), identified the structural changes in convective clouds associated with aerosol (Koren et al., 2005), estimated the direct radiative effect of aerosols over the global oceans (Remer et al., 2005a) and determined the anthropogenic component of the aerosol optical thickness from MODIS (Kaufman et al., 2005a).

Even with these successes, we realize that there is room for improvement in the algorithm and its products. In Collection 005, which should have been operational by now, we implement a snow mask for land that will eliminate subpixel snow contamination (Li et al., 2005), fine tune the cloud mask and some of the aerosol model assumptions. We are also busy working towards even more fundamental changes that will address nonsphericity in the ocean retrieval of dust, reduce the offset over land introduced by incorrect assumptions of the land surface, restructure the land inversion in order to produce a more meaningful fine mode fraction over land and correct for the thin cirrus that is now contaminating our product.

Contents:

A. Validation of existing products (Collection 003 and 004)

Although the data available currently at the DAAC is Collection 004, some of the results in the sections below also contain results from the previous collection, Collection 003.

Collection 004 data is a description that applies to products created from two different versions of the MODIS aerosol algorithm code. All of Aqua data and the Terra data processed after January 1, 2004 were created with Version 4.2.2. The Terra data before January 2004 were created with Version 4.1.0. The difference mostly concerns the type of cloud mask applied over land. In the earlier version we used the "Wisconsin cloud mask". This is the standard MODIS cloud mask that is available as MOD35. In the later version we implemented an internal cloud mask based on a combination of spatial variability and tests using the 1.38μm channel. Over ocean, the spatial variability cloud mask described in Martins et al. (2002) is used for all Collection 004 data.

The best documentation to the Collection 004 algorithm and products can be found in Remer et al. (2005b). It includes a section on product validation. However, only Terra data is validated in that paper and collections 003 and 004 are combined in the two-year data set. A second validation paper that includes Aqua and separates by collection number is Ichoku et al. (2005).

A.1. Global Optical Depth Retreivals from Terra, land and ocean.

Applying the Ichoku et al. (2002) method to collocating Terra-MODIS retrievals with AERONET observations we are able to match almost 6000 points over land and more than 2000 points over ocean from two years of MODIS data. The matched points were binned in AERONET optical depth bins and are plotted in Figure A1. The regression lines and correlations shown in the figure are calculated from the unbinned data. The dashed lines represent the pre-launch expected uncertainty of the retrieval. We expect over land to retrieve optical depth to within $\pm 0.05 \pm 0.15\tau$ and over ocean to within $\pm 0.03 \pm 0.05\,\tau$, where τ is the optical depth. In Remer et al. (2005b) we show that globally, 1 standard deviation (66%) of the retrievals fall within the expected uncertainty. We also show in the same paper regional biases that are not apparent in the global plots.

We conclude that the ocean algorithm is meeting expectations, except perhaps in certain situations such as dust. The land algorithm is also meeting expectations, except that there is a definite positive bias for low aerosol AOT and a negative bias at high aerosol AOT.

These identified problems are well-understood. Levy et al. (2003) discuss retrieving aerosol properties of dust. Dust nonsphericity introduces greater scatter in the AOT retrieval, but no long-term bias in mid-visible channels. However, it does bias size parameter retrievals (Section A.3). Plans to mitigate problems with dust retrieval are discussed in Section D.3. Over land the positive bias at low AOT is due to incorrect surface assumptions and failure to permit negative retrievals. We describe our plans to alleviate this bias in Sections D.1 and D.2. Over land the negative bias at high AOT is due to erroneous single scattering albedo with not enough light absorption as described in

Ichoku et al. (2003). Better aerosol models were introduced into Collection 004 to solve this problem and their distribution is refined in Collection 005 (Section C.3)

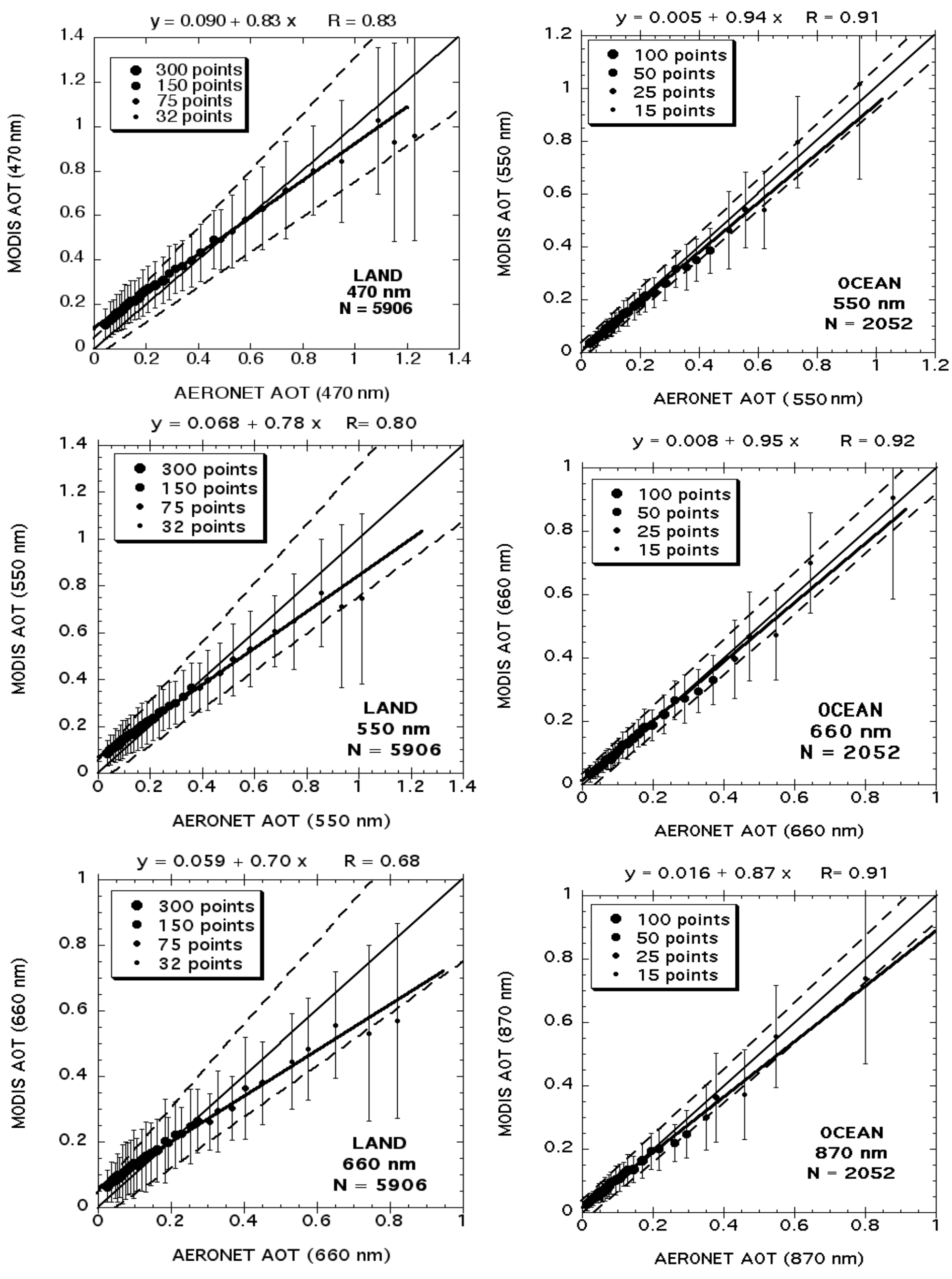


Figure A1. Validation plots taken from Remer et al. (2005b). Land on the left and Ocean on the right, for three wavelengths in each case. The dashed lines represent expected uncertainty. The vertical bars denote 1 standard deviation about the mean value in each bin.

A.2. Global Optical Depth Retreivals from Terra and Aqua, land and ocean.

An evaluation of the MODIS AOT retrievals against AERONET values is described in Ichoku et al. (2005) and shown in figure A2. This evaluation differs from the one of the previous section in the following three ways: Fig. A2 (a) includes three years of data, not two, (b) shows Aqua data in addition to Terra data and (c) separates data from Collection 003 and 004, while Fig A1 mixes collections. Note that Terra V004 is the same algorithm as Aqua V003.

The conclusions are the same as in Section A.1. The added information shows us that Aqua performs as well as Terra in terms of midvisible AOT. However, it appears as though Terra V004 over land actually performs worse than Terra V003 over land. The reason for this apparent decrease in retrieval accuracy is that one of the major differences between the two versions is the extension of the land retrieval to brighter surfaces. The range and number of MODIS aerosol retrievals increases significantly in Terra V004. However, these extra retrievals are marked by lower Quality Flags. Quality Flags were not considered in Fig. A2. Thus, lower quality retrievals are mixed in with the standard product for Terra V004 and Aqua V003.

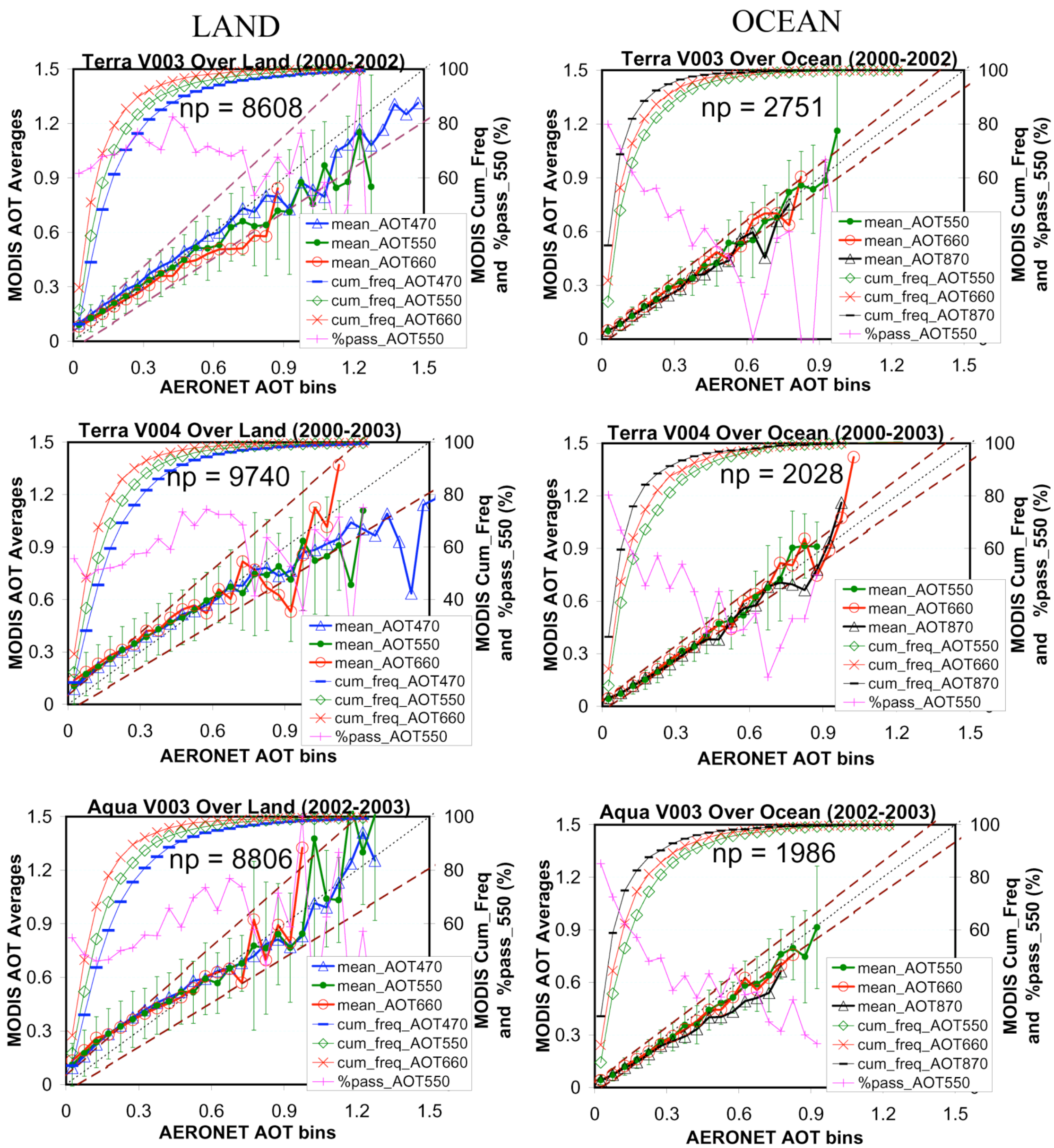


Figure A2. Modified scatter plots of MODIS global class average AOT (based on collocated AERONET AOT bins) against the AERONET AOT bin center values, over land (at 470, 550, 660 nm wavelengths) and ocean (at 550, 660, 870 nm wavelengths). T003 and T004 are Terra Collection 003 and 004, respectively. A003 is Aqua collection 003, which is equivalent to Terra 004. The standard deviations of the AOT classes for MODIS are shown as error bars only for the 550 nm curves (to limit clutter). The dotted diagonal line is the 1-to-1 line, while the pair of near diagonal broken lines are the bounds of the uncertainty envelops. The total number of data points (*np*) used in each data group is shown on each panel, while the cumulative counts of data points in each class are plotted at all wavelengths represented. The percent proportion of MODIS AOT at 550 nm falling within the specified uncertainty bounds in each class are plotted (*%pass_550*).

A.3. Global Fine Mode Fraction retrievals, over ocean

Kleidman et al. (2005) describe validating MODIS retrievals of fine mode fraction over ocean against two independent retrievals using AERONET data. Figure A3 shows a scatter plot of MODIS retrievals of fine mode fraction against AERONET retrievals using the O'Neill method. The O'Neill method uses the spectral curvature of the direct sun measurements to determine fine mode fraction. This differs significantly from the Dubovik method of inverting sky radiance. The advantage of the O'Neill method is the greater frequency of inversions.

The results show a definite correlation between the two retrievals with MODIS over estimating fine fraction for large particle aerosols and underestimating for small particles. The overestimation for large particles will be much reduced with new Look-Up Tables in the ocean algorithm (Section D.3.)

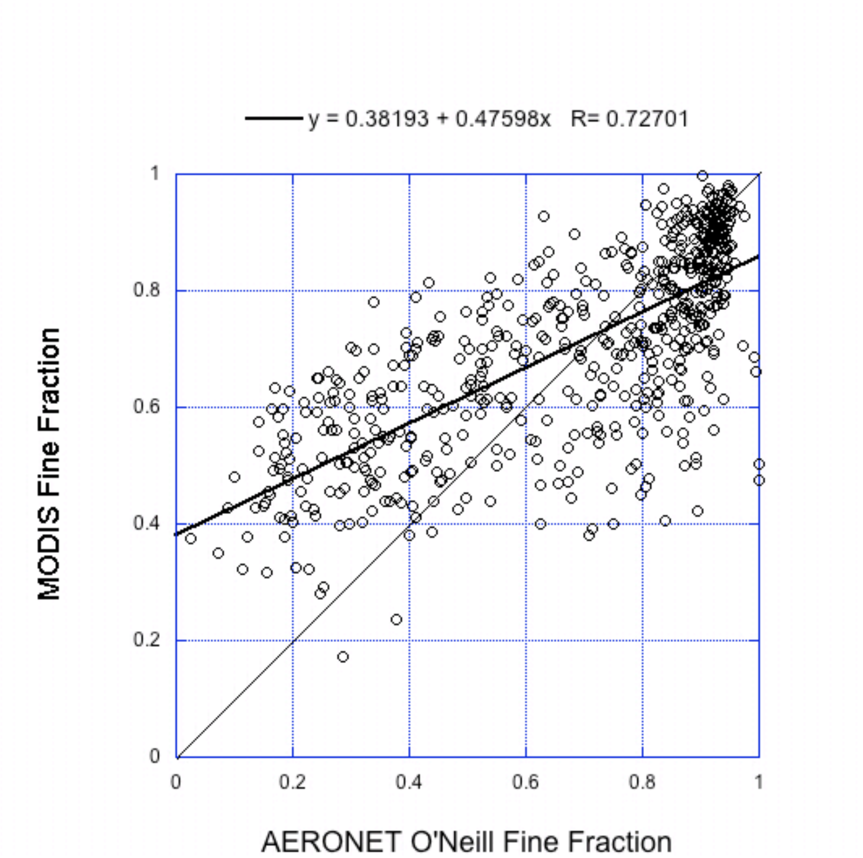


Figure A3.

A.4. Regional Validation Studies: ACE-Asia and CLAMS

Analyses from two regional validation studies: ACE-Asia and CLAMS were recently published in papers by Chu et al. (2005) and Levy et al. (2005), respectively.

The ACE-Asia results include validation of the spectral MODIS AOT retrieval against the Ames Airborne Tracking Sunphotometer across a wide spectral range that includes the 1.63 μm channel (figure A4). The results show excellent agreement between MODIS and the sunphotometer for situations dominated by either marine aerosols or pollution-type aerosol over both ocean and land. Situations dominated by desert dust posed a more difficult situation. Chu et al. (2005) also discuss the sensitivity of the MODIS size parameter retrieval to small perturbations in instrument calibration. They show that the ACE-Asia period took place during the short period of time when MODIS was using Side B electronics, and this resulted in retrievals of fine mode fraction that were too large and effective radius that were too small, as compared to other years in the same region (Figure A5). The sensitivity to instrument calibration increases for decreasing AOT. Thus, the side B period in Terra-MODIS's lifetime (Sept 2000 to June 2001) will mostly affect size retrievals of the background marine aerosol, causing MODIS to underestimate particle size.

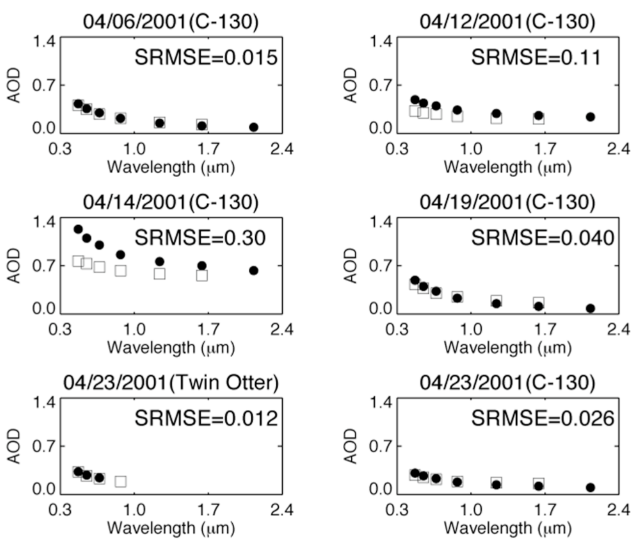


Figure A4. Spectral optical thickness retrieved by MODIS (black dots) and the AATS (open squares) at all available coincident measurements during ACE-Asia. When only 3 wavelenghs are shown from MODIS the retrieval took place over land. Both the AATS-6 with six channels and the AATS-14 with fourteen channels are shown. Agreement is within expectations for BOTH land and ocean retrievals. Only the dust event of 04/14/2001 over ocean caused large error in the MODIS retrieval.

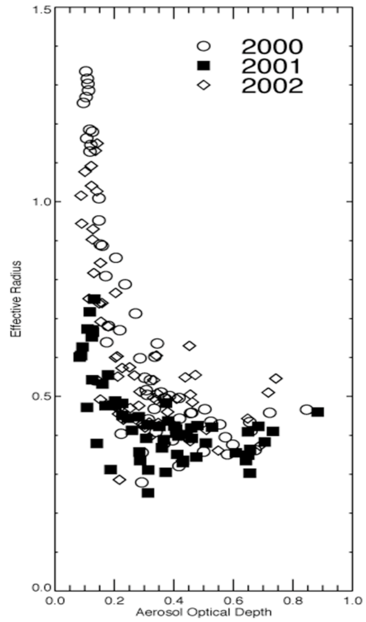
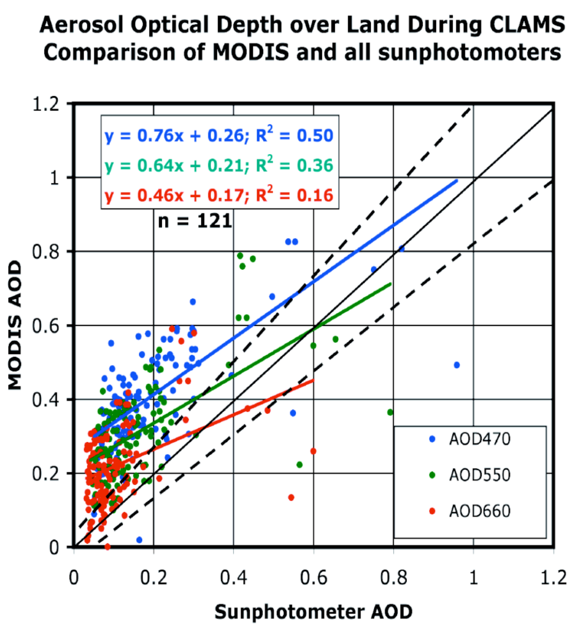


Figure A5. Effective radius as function of AOD for three years of MODIS retrievals in the ACE-Asia region. Note that 2001, the ACE-Asia period, reports much lower particle size than other years. This has been traced to small perturbations in the instrument calibration during that time period.

The CLAMS results illustrate some of the trends seen in the global validation plot (fig. A1). In Figure A6 (right), we see MODIS collocated with a wide variety of sunphotometer measurements including AERONET, AATS and handheld microtops. Some of these sunphotometers permit validation at longer wavelengths. Over ocean, the CLAMS retrievals, like the global ocean retrievals are falling within prelaunch expectations for all wavelengths. Over land, at low AOT, we see a strong positive offset that is only hinted at in the global validation. Levy et al. analyze the CLAMS results in depth to show how the surface type in the CLAMS area does not conform to assumptions in the retrieval. In Section D.1. we describe the development of more robust surface reflectance assumptions that are expected to mitigate this problem.



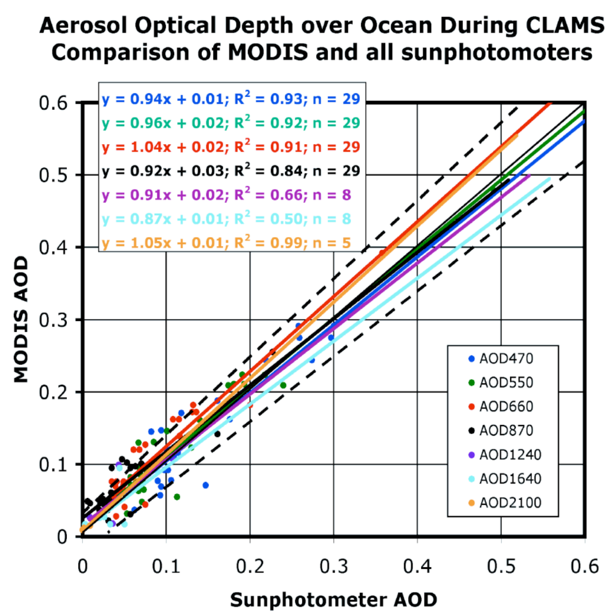


Figure A7 CLAMS validation over land (left) and over ocean (right).

A5. Investigation of potential cloud contamination

The MODIS algorithm produces a 10 km aerosol product after first screening for clouds at 500 m resolution. The screening consists of a spatial variability test for most clouds and the use of the 1.38 μm channel to detect cirrus. An example of the cloud mask at work over land is shown in Figure A7. In the lower left image orange squares denote the 1 km pixels identified as cloud by the independent cloud microphysics algorithm (Platnick et al., 2003). The green squares in the lower left image denote the 500 m reflectances of the pixels actually used by the aerosol retrieval. The large colored squares in the upper right image show the MODIS 10 km product generated from the 500 m reflectances. Superimposed on the 10 Km squares are the 1 km clouds. Note that the aerosol cloud mask avoids bright land surfaces as well as clouds.

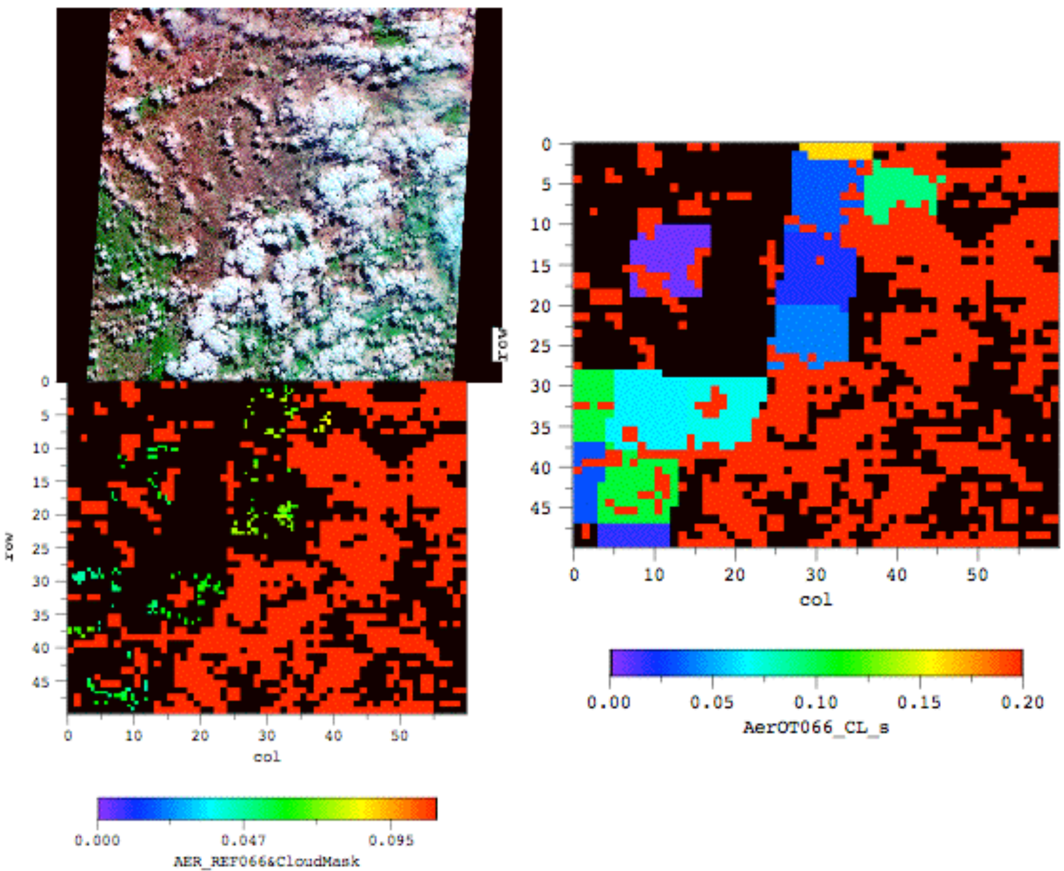


Figure A7. Courtesy of Alexander Marshak. ASTER image in upper left. 500 m pixel reflectance used in the aerosol retrieval (lower left). 10 km aerosol optical thickness retrieval for the same image. Orange squares are clouds determined by the independent cloud microphysical retrieval. Note how the algorithm can retrieve aerosol in between clouds.

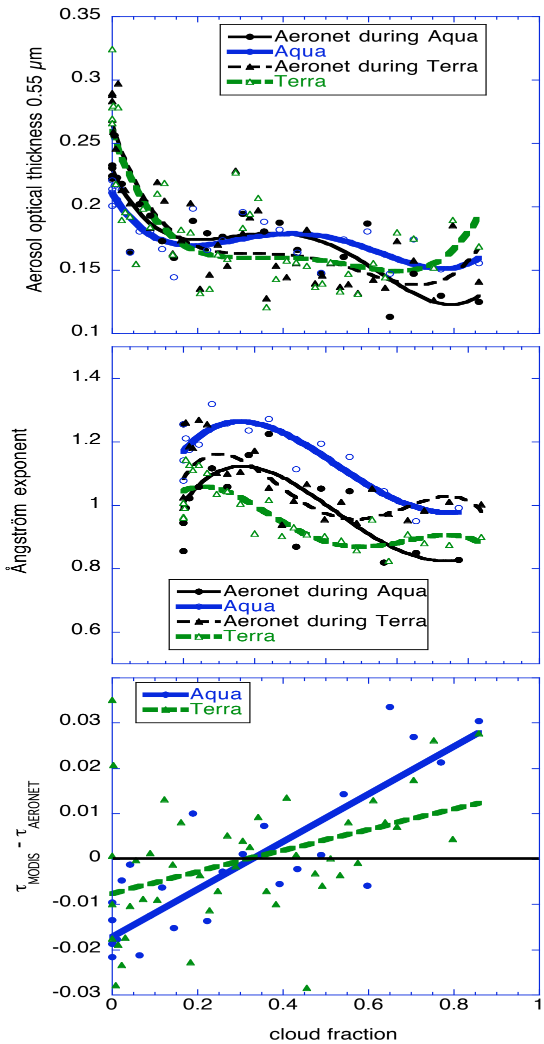


Figure A9.

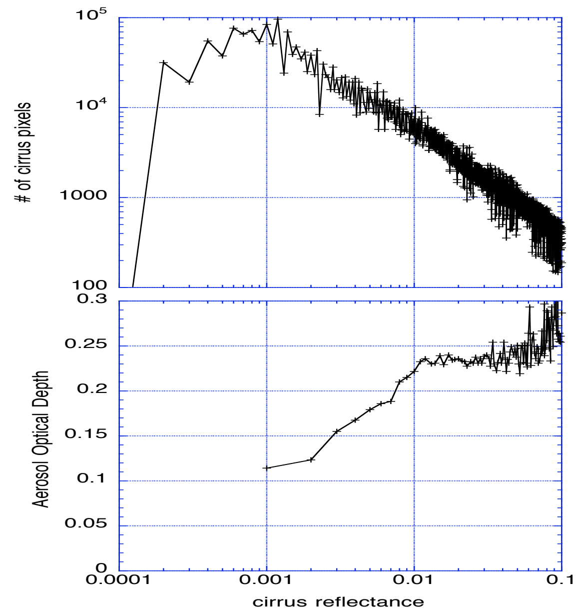


Figure A8. Example of the analysis of cirrus contamination. Top: histogram of the cirrus reflectance measured by MODIS over the globe for one day (April 1st 2004). Each point is the average over a 10 km grid box. Note the logarithmic scale. Bottom: Average aerosol optical thickness (AOT) as a function of a given range of cirrus reflectance (i.e. first point is the average AOT for cirrus reflectance of 0-0.001, second for 0.001-0.002 etc.) Cirrus contamination is measured as the elevation of the AOT above its value for the lowest cirrus reflectance interval.

One problem with the aerosol cloud mask is that the threshold on the 1.38 μm test is 0.01. This means that all reflectances below this cutoff will be retrieved as aerosol, with some thin cirrus included. We cannot set the threshold to zero, because of noise in the channel and also because dust can also produce a signature at 1.38 μm. Recently Kaufman et al. (2005d) investigated the accumulated effect of permitting thin cirrus into the aerosol retrieval (Figure A8). They found, over ocean, that cirrus contamination increases global mean aerosol optical thickness by 0.015 (about 10 to 15%).

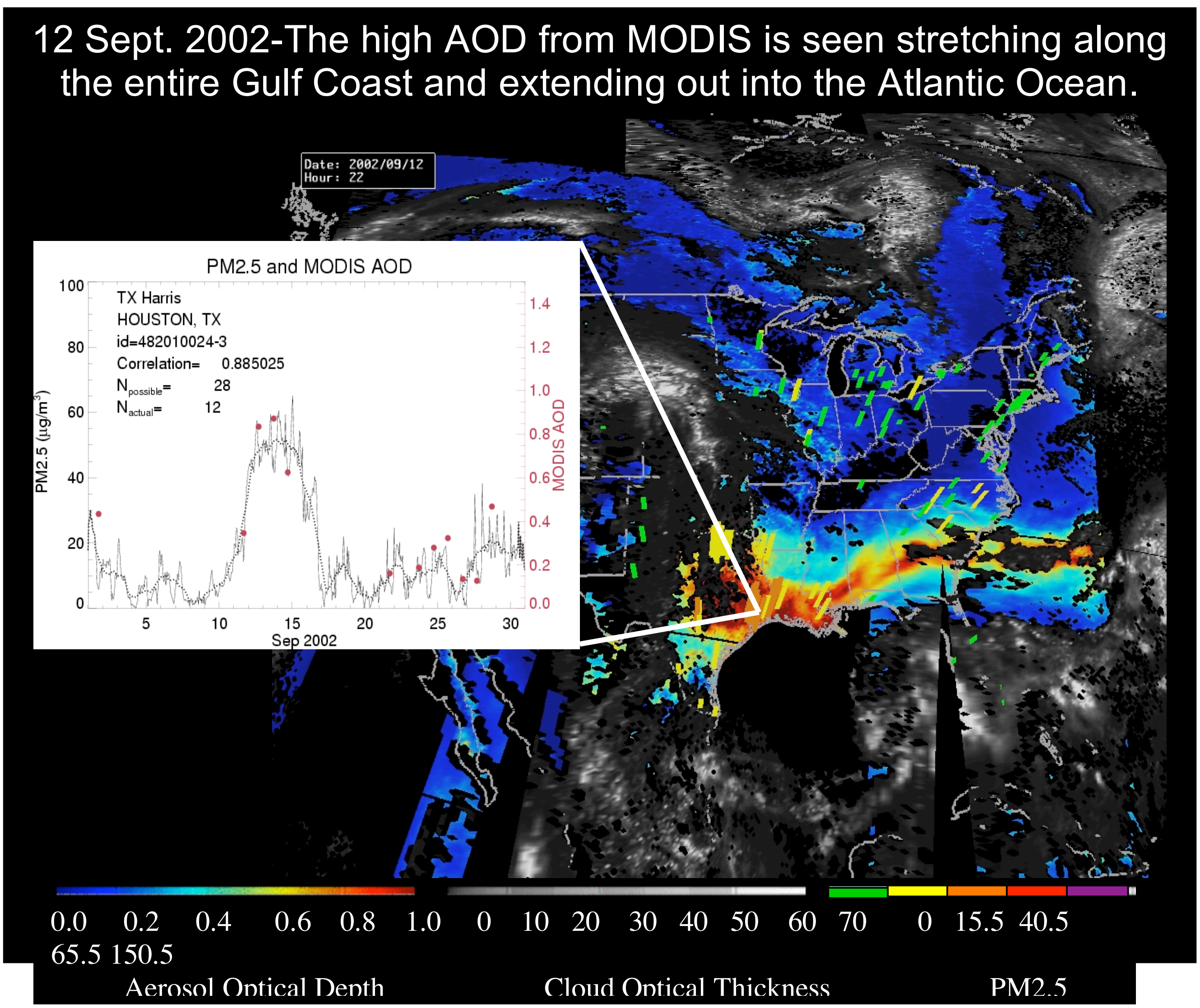
Kaufman et al. (2005d) also examined possible cloud contamination using the difference between MODIS and AERONET measurements (Figure A9). The study showed an increase in MODIS AOT, relative to AERONET as cloud fraction increased. However, because Angstrom Exponent did not increase at the same time, simple cloud contamination in the MODIS product CANNOT be the root cause of the relationship.

B. Selected Applications Using Existing Products

The MODIS aerosol products are widely used through out the scientific community, and not just by the MODIS aerosol team. We found 28 publications from 2004 that were based on MODIS aerosol products (Kaufman et al. 2005d). These studies span applications as varied as air quality to climate change.

B.1. MODIS aerosol products as operational Decision Support Tools for the EPA

MODIS aerosol products were chosen as a decision support tool by the EPA. The strength of the MODIS product for operational forecasting is a combination of its accuracy and daily coverage. In a joint project, the MODIS aerosol team at GSFC joined with NASA Langley, the EPA, NOAA and the University of Wisconsin to produce a suite of enhanced imagery based on the MODIS aerosol over land product. These products are provided in near real time to forecasters across the country and are used to make operational air quality forecasts (Al-Saadi et al., 2005). Other studies, both within the group and independent of it, demonstrate the effectiveness of the MODIS product as an air quality tool (Chu et al., 2003, Wang and Christopher, 2003; Engel-Cox et al., 2004).



B.2. Estimation of dust transport from western Sahara over the Atlantic.

Using a combination of MODIS aerosol products, NCEP winds and AERONET data, Kaufman et al. (2005c) estimated the mass transport of dust aerosol across the Atlantic basin. MODIS aerosol optical thickness and fine mode fraction were used to estimate the dust component of the total mass concentration. AERONET and MODIS optical thickness data correlated with NCEP wind speeds were used to estimate transport height (Koren and Kaufman, 2004). The results show that **240**±80 Tg of dust are transported annually from Africa to the Atlantic Ocean, **140**±40 Tg are deposited in the Atlantic Ocean, **50** Tg fertilize the Amazon Basin, 4 times as previous estimates thus explaining a paradox regarding the source of nutrition to the Amazon forest, **50** Tg reach the Caribbean and **20** Tg return to Africa and Europe. The results are compared favorably with dust transport models for maximum particle diameter between 6 and 12 μm. (Figure B2)

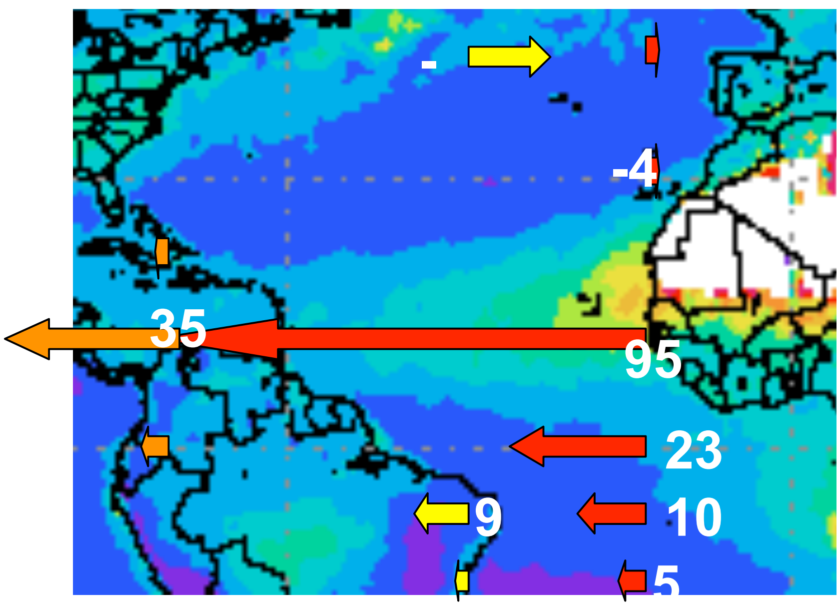


Figure B2. Dust transport for the May-September period across the Atlantic derived from MODIS aerosol products. The numbers are mass units of Tg. (Kaufman et al., 2004c).

B.3. Estimation of aerosol direct and indirect effects on climate

The MODIS aerosol products have spawned a resurgence in aerosol-climate studies. Contributions from our group include:

- identifying the inverse relationship between smoke aerosol and clouds in the Amazon Basin, and estimating the resulting *change in sign* of the aerosol forcing in that area (Koren et al., 2004). Figure B3.
- identifying the positive correlation between aerosol amount and cloud coverage of shallow clouds over the Atlantic and estimating the local radiative forcing caused by this second indirect effect (Kaufman et al., 2005b). Figure B4.
- identifying the structural changes in convective clouds associated with increasing aerosol amounts over the Atlantic and the potential for aerosol to change precipitation patterns and atmospheric circulations (Koren et al., 2005). Fig. B5
- estimating the direct radiative effect of aerosols over the global oceans (Remer et al., 2005a). Figure B6.
- estimating the *anthropogenic* component of the MODIS aerosol optical thickness over the global oceans and the resulting anthropogenic aerosol direct radiative forcing (Kaufman et al., 2005a).

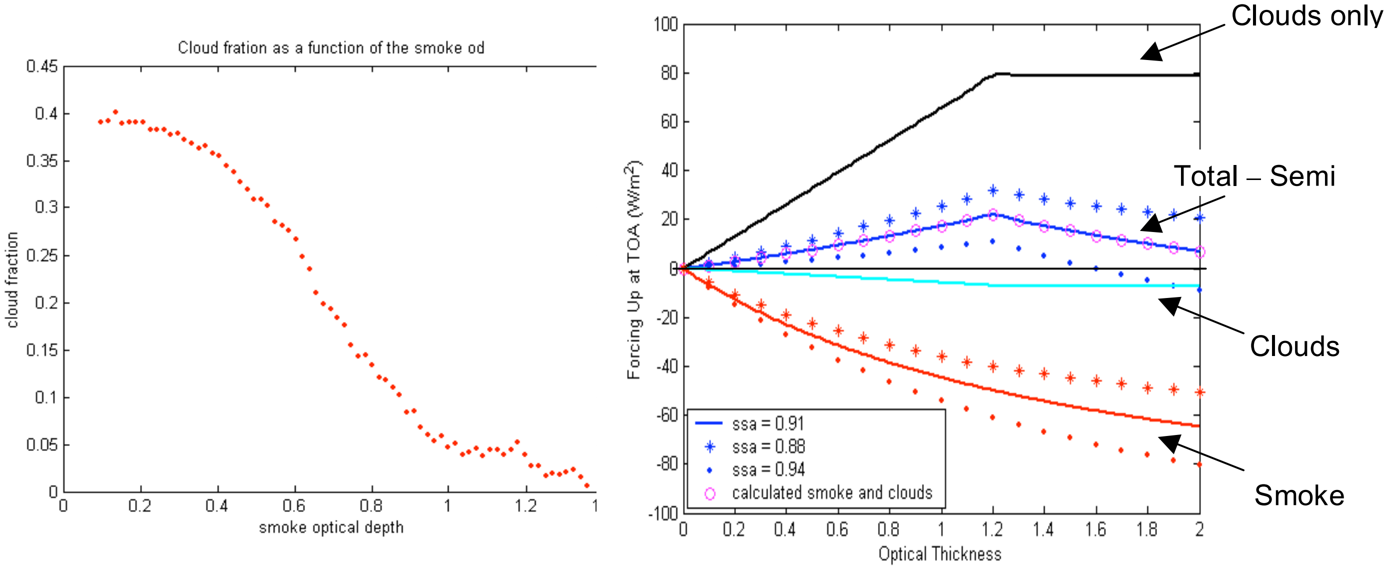


Figure B3. Cloud fraction as function of smoke optical depth (left) and total radiative effect at TOA in Wm-2 by both direct and semi-direct effects (right). Note that the total smoke effect that includes both direct radiative effects plus the effect of reduces cloud fraction causes a shift of forcing from negative to positive. (Koren et al., 2004).

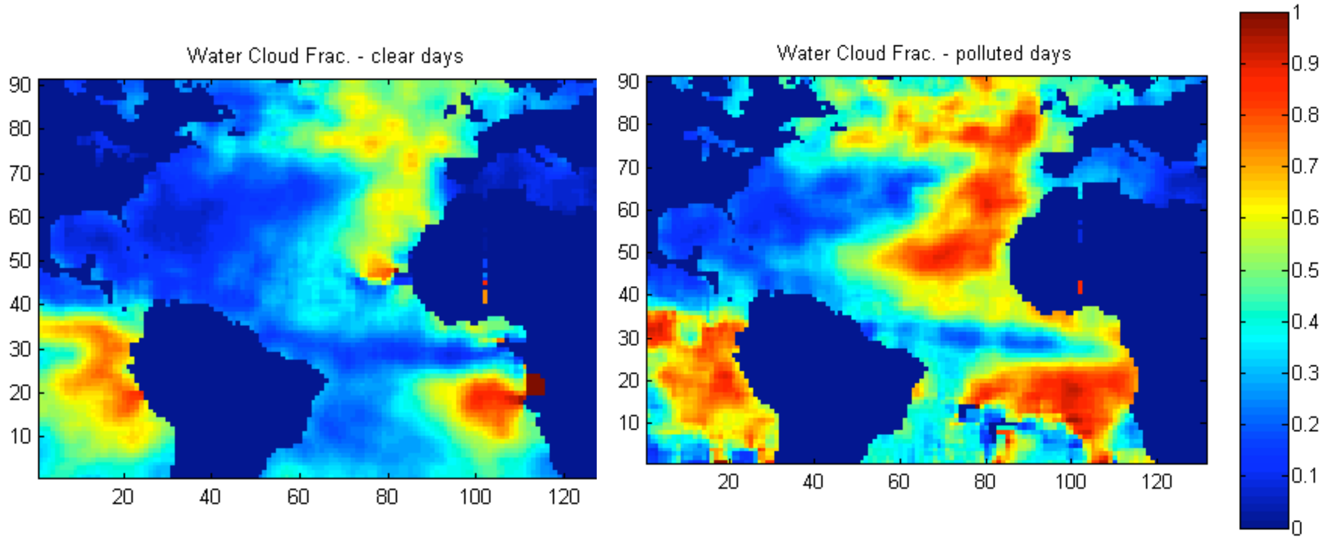


Figure B4. The cloud fraction of water clouds increases substantially on polluted days from initial values on low aerosol days. Kaufman et al. (2005b).

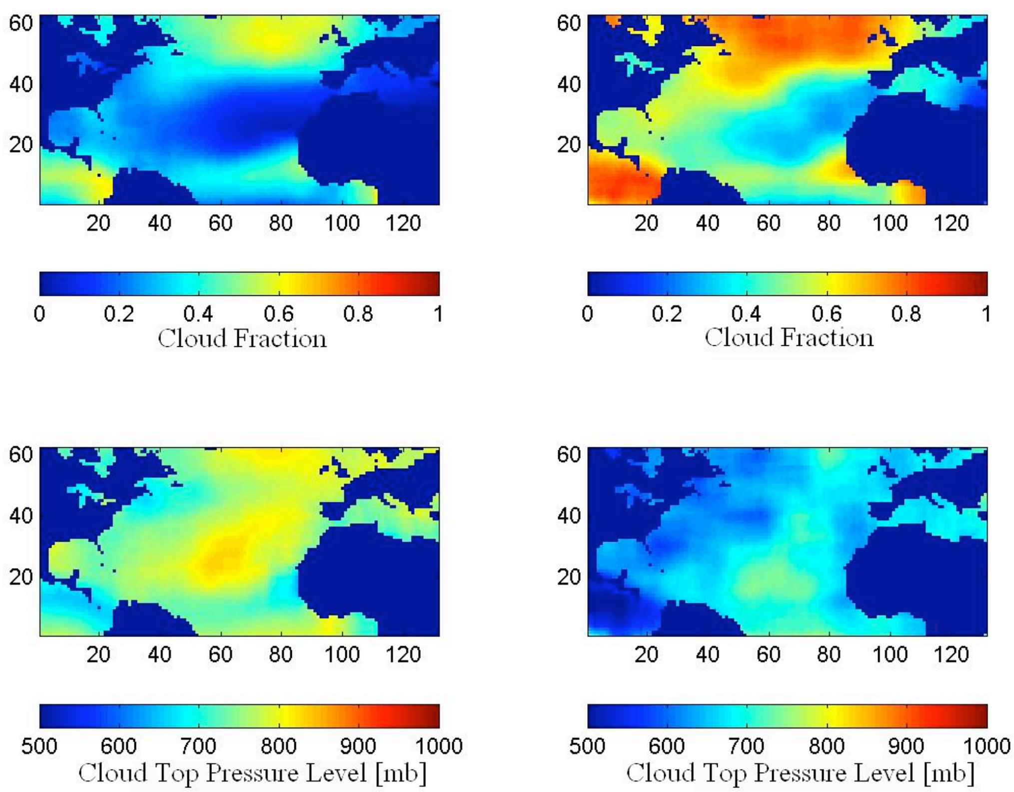


Figure B5. Cloud fraction (top) and cloud top pressure (bottom) of convective clouds for clean conditions (left) and polluted conditions (right). Koren et al., (2005).

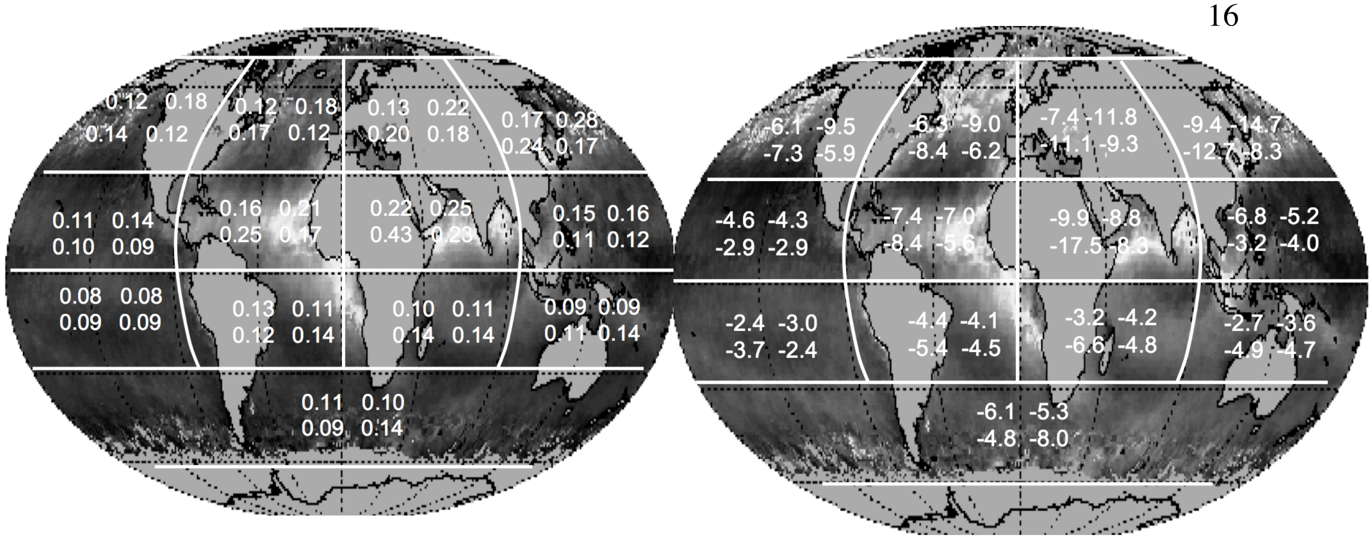


Figure B6. MODIS measured seasonal mean aerosol optical thickness (left) and measurement-based estimates of direct radiative effect at TOA in Wm-2 (right). In each region, read the values from left to right, beginning with the northern winter value in the upper left corner.

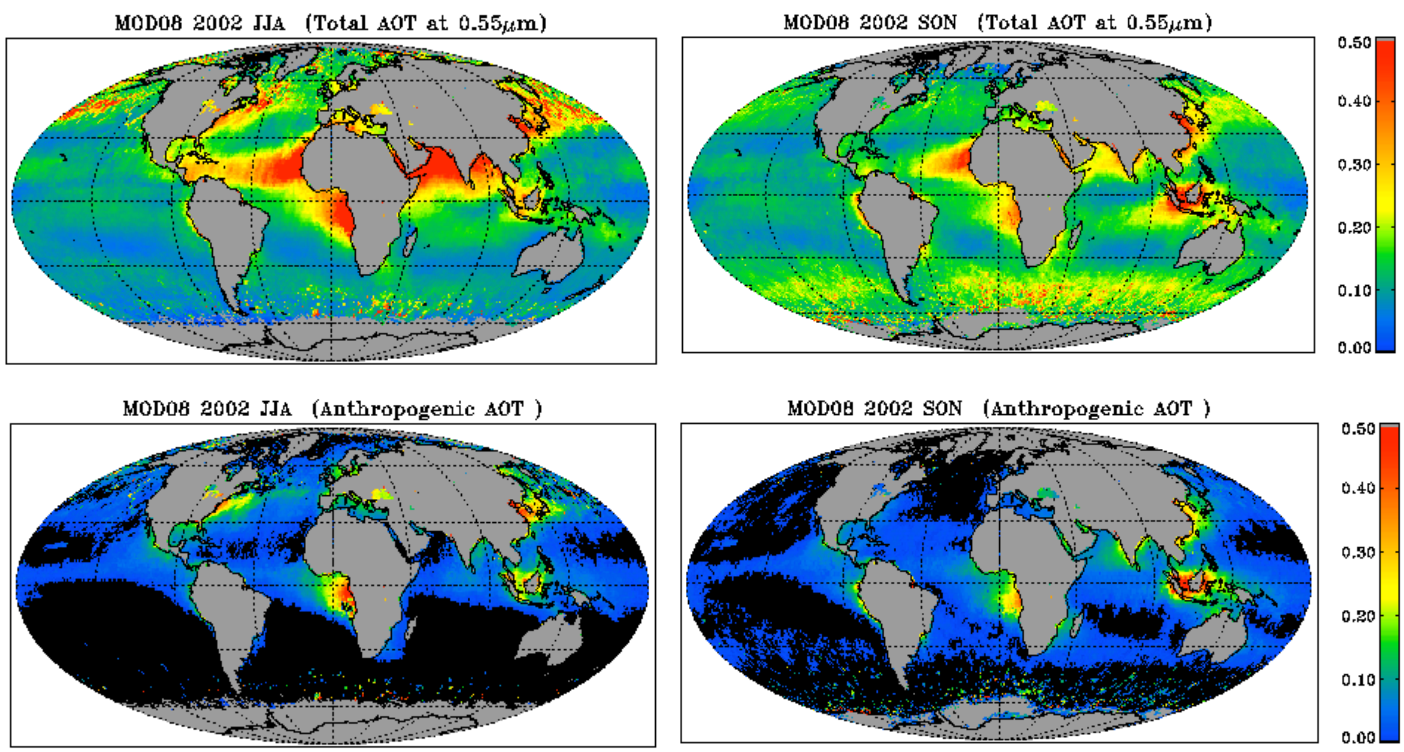


Figure B7. Total and anthropogenic component of the global AOT from MODIS aerosol products. Kaufman et al., (2005a).

C. Highlights of Collection 005.

We delivered our updated code for the Terra Collection 005 reprocessing, as requested in June of 2004 with the expectation that reprocessing would begin within 5 to 6 months. Unfortunately, other atmospheric algorithms besides the aerosol algorithm have experienced severe delays, so that atmospheres reprocessing has not yet begun. We could not wait on one of the Collection 005 updates. Therefore we have already implemented the change described in Section C.3 with an emergency patch. However, all other 005 changes are still waiting to be implemented in the operational processing stream. In addition to the three changes described below, we have also corrected units for the CCN product, redefined some products and have performed general maintenance and "housecleaning activities."

The updates to collection 005, while important, are not structural or fundamental in nature. We have already begun to develop major algorithm changes for Collection 006. These are described in Section D.

C.1. Land: Subpixel snow mask implemented.

Aerosol retrieval from satellites requires assumptions about the surface reflectance in order to separate the radiance signal originating in the atmosphere from that originating from the Earth's surface. Over ocean it is relatively easy. Over land it is much more difficult. The MODIS aerosol retrieval over land is limited to pixels where our assumptions about the land surface reflectance will hold. These tend to be dark, vegetated pixels. The over land algorithm currently does not work over bright deserts or over snow. Since launch, the aerosol algorithm has relied on a snow mask based on other MODIS products and auxilliary data that is passed to us through the MOD35 product. This snow mask effectively identifies fully snow covered pixels, such that can be seen in Figure C1 as the black regions in the most northerly latitudes of the northern hemisphere in April 2004. However, just south of the properly masked snow fields lies a band of bright colors representing aerosol optical thicknesses greater than 0.60. These high aerosol values are not real, but an artifact caused by snow-contaminated pixels slipping through the standard snow mask.

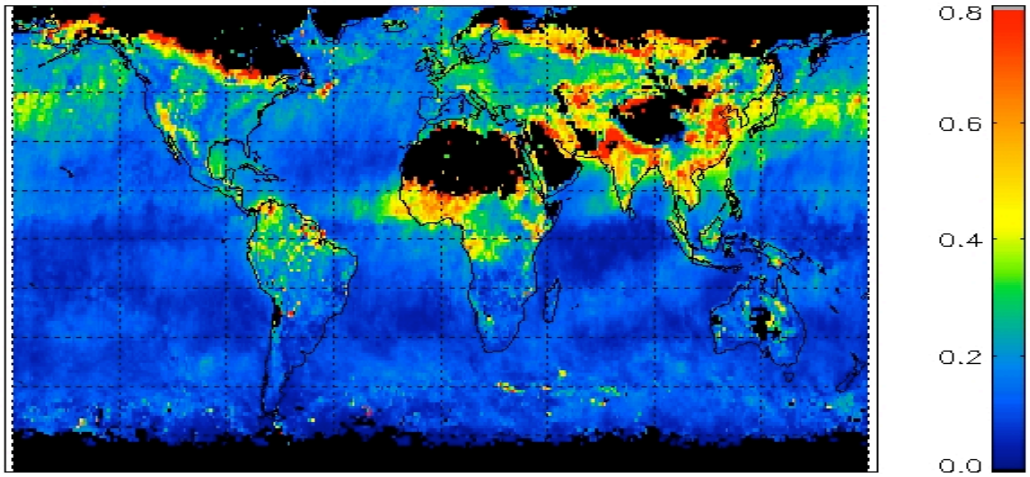


Fig. C1. A sample Level 3 monthly-mean global aerosol optical depth image retrieved from the Terra MODIS data for April 2004.

We have developed a new method that is sensitive to pixels only partially filled with snow (Li et al., 2005). The method is based on the fact that snow is darker at 1.24 μm than at 0.86 μm, but almost all other surface types exhibit the reverse spectral dependence. We apply the normalized difference ratio,

$$R = [\rho^*_{0.86} - \rho^*_{1.24}] \ / \ [\rho^*_{0.86} + \rho^*_{1.24}], \qquad (1)$$

and couple the ratio to a threshold of the 11 μm channel brightness temperature to identify snow-contaminated pixels. The result effectively eliminates snow contamination in the aerosol land product without accidentally masking out perfectly good pixels in other regions. An example is shown below in Figure C2.

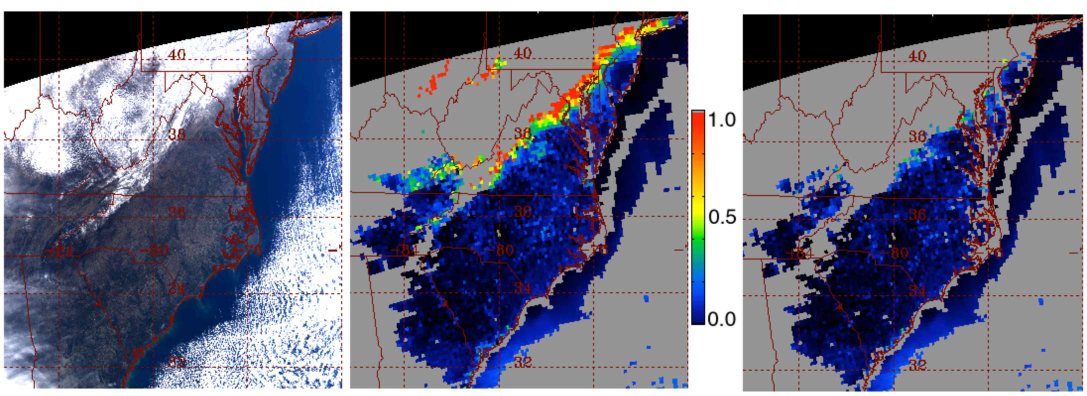
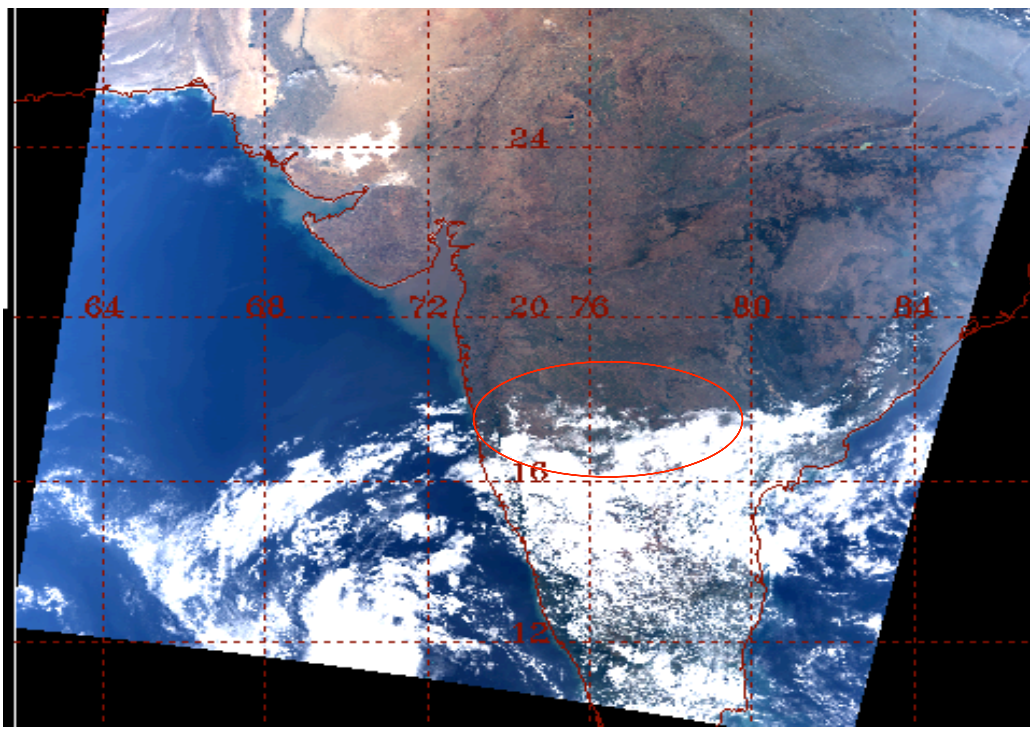


Fig. C2. (a) – An Aqua MODIS image over North America on February 8, 2004; (b) the derived aerosol optical depth image using the operational MODIS aerosol algorithm; and (c) the aerosol optical depth image with improved snow masking.

C.2. Land: Cloud mask adjusted and QA flag set to 0 in some situations.

Masking clouds without masking aerosol events remains one of the most challenging issues faced by the aerosol retrieval algorithms. At Terra launch, the aerosol retrievals relied on the standard cloud mask products available in MOD35. Almost immediately we realized that these products were not going to be adequate. A new cloud mask based on a spatial variability test, supplemented by cirrus tests using the 1.38 μm channel and a few remaining MOD35 products, was implemented in the over *ocean* aerosol algorithm (Martins et al., 2002). The mask proved to be very successful, especially after adjustments to the cirrus identification part of the algorithm (Gao et al. 2002). All of Collection 004 data over ocean, both from Terra and Aqua, were produced using this cloud mask.

A separate but similar cloud mask for masking clouds over land was developed later and not implemented until November 2002. The spatial variability cloud mask over land improved the aerosol retrievals, especially when it came to confusing heavy aerosol with cloud. However, isolated, residual cloud contamination in the product remained. For Collection 005, we have made a few adjustments to the technique, but maintained the general philosophy and structure of using spatial variability tests coupled with threshold tests only in the 1.38 μm channel. This seems to remove isolated artifacts in the retrieval. For example, in Figure C3, the red spots associated with clouds over India in a relatively clean area are removed with the new cloud logic.



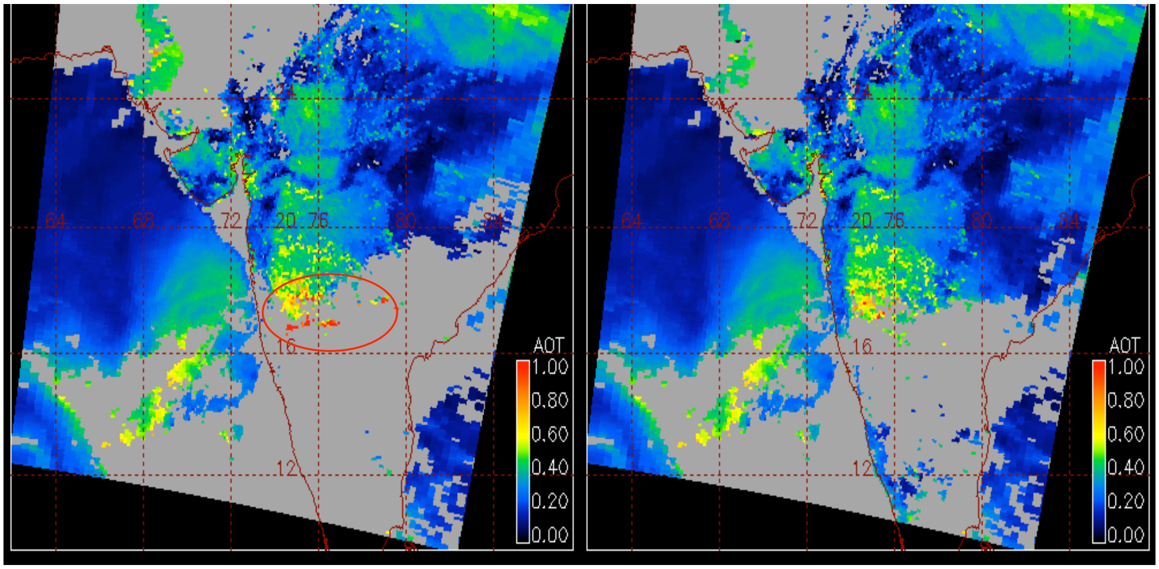


Figure C3. Images from MOD04 from year 2000, day 337, time 0555 located over India. The top image is a true color rgb with the red oval highlighting the edge of a cloudy area. The same area is identified by the oval in the lower left image, which shows aerosol optical thickness retrieval available in Collection 004. The bright red spots are an artifact of cloud contamination. These are eliminated in the lower right image, which was produced with Collection 005 software and improved cloud masking logic over land. The increased number of retrievals in the Collection 005 image result from permitting negative values in the 1.38 µm channel, as described in Section C.3 below.

C.3. Land and Ocean: Negative reflectances in 1.38 µm channel permitted.

The aerosol retrieval algorithms continually check incoming data before using the L1B radiances to derive aerosol. Pixels identified as containing bad data in specific channels are discarded and fill values placed in the final product. One important channel contains the 1.38 µm reflectance, which is used to identify cirrus in the pixel. This channel is especially sensitive to cirrus clouds because in the absence of particles high in the atmosphere the channel returns reflectances near zero due to the strong water vapor absorption at this wavelength. As it turns out, near zero reflectance could either be slightly positive or slightly negative. The aerosol algorithm required incoming reflectances in this channel to be non-negative. If negative values were found, no aerosol retrieval was attempted. The result was that in cirrus free conditions when the 1.38 µm was slightly negative the aerosol algorithm would often fail make an aerosol retrieval. Many retrieval opportunities were lost. We have adjusted the checking of incoming data to permit slightly negative values. The result is the recovery of many additional retrievals, especially over land. Figure 7 illustrates the increased number of retrievals.

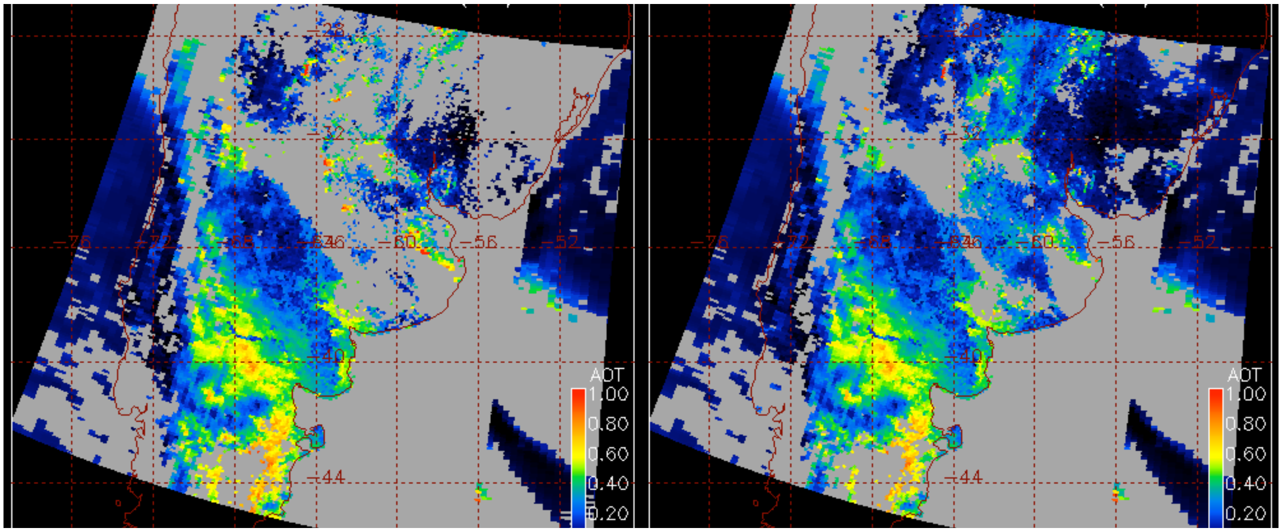


Fig.C4 Image of aerosol optical thickness from MOD04 from year 2000, day 337, time 1425 located over South America. On the left is the retrieval from the 004 collection, while on the right, from the 005 collection. Note the increased range of the aerosol retrieval in Brazil. The extended range of retrieval is due simply to permitting slightly negative values of 1.38 μm reflectance to be processed. Note that the image on the right also benefits from the adjusted cloud mask logic over land described in Section 2, and therefore several patches of high aerosol optical thickness associated with cloud contamination are eliminated.

D. Proposed Changes for Next Delivery

Because of the delay in implementing Collection 005 algorithms, it is unclear when the next delivery will take place. However, we feel at least one more major reprocessing is necessary for the aerosol algorithms. There are three main areas which we are working on: 1) New Look Up Tables for the ocean retrieval. 2) New land surface reflectance estimates 3) New structure to the land algorithm.

D.1. New ocean look up tables.

Following over 10 years of AERONET retrievals we now have much better knowledge of the aerosol properties found near ocean sites. We are creating new look up tables for the coarse mode aerosol with more realistic refractive index values for the sea salt models and using spheroid representation for the dust models. Preliminary testing indicates that the new salt models will result in almost no difference to AOT retrievals but a reduced fine mode fraction for large mode dominated aerosols. This will bring our validation into better alignment when compared against AERONET (See figure A3).

The dust models present a greater challenge. The spectral signature of the spheroids for dust is not favored over the spectral signature of the sea salt models in the retrieval. The inversion does not choose the spheroid models in a dust situation, even though the inversion needs the spheroid phase functions to produce a more accurate retrieval. We are currently investigating different methods that will “encourage” the inversion to choose the proper model.

D.2. New land surface reflectance estimates

The positive offset in the validation plots over land (Figs. A1, A2) give us some concern, even though globally the offset is within prelaunch estimates as long as only high quality retrievals are used. This is because regionally (Fig. A7) the offset can be large even for high quality data. We are in the process of exploring different relationships between the visible channels and the 2.13 channel that form the basis of the land surface reflectance estimates. More realistic estimates will be implemented after further testing is concluded. Figure D1 demonstrates the possible improvement to be realized by making this change.

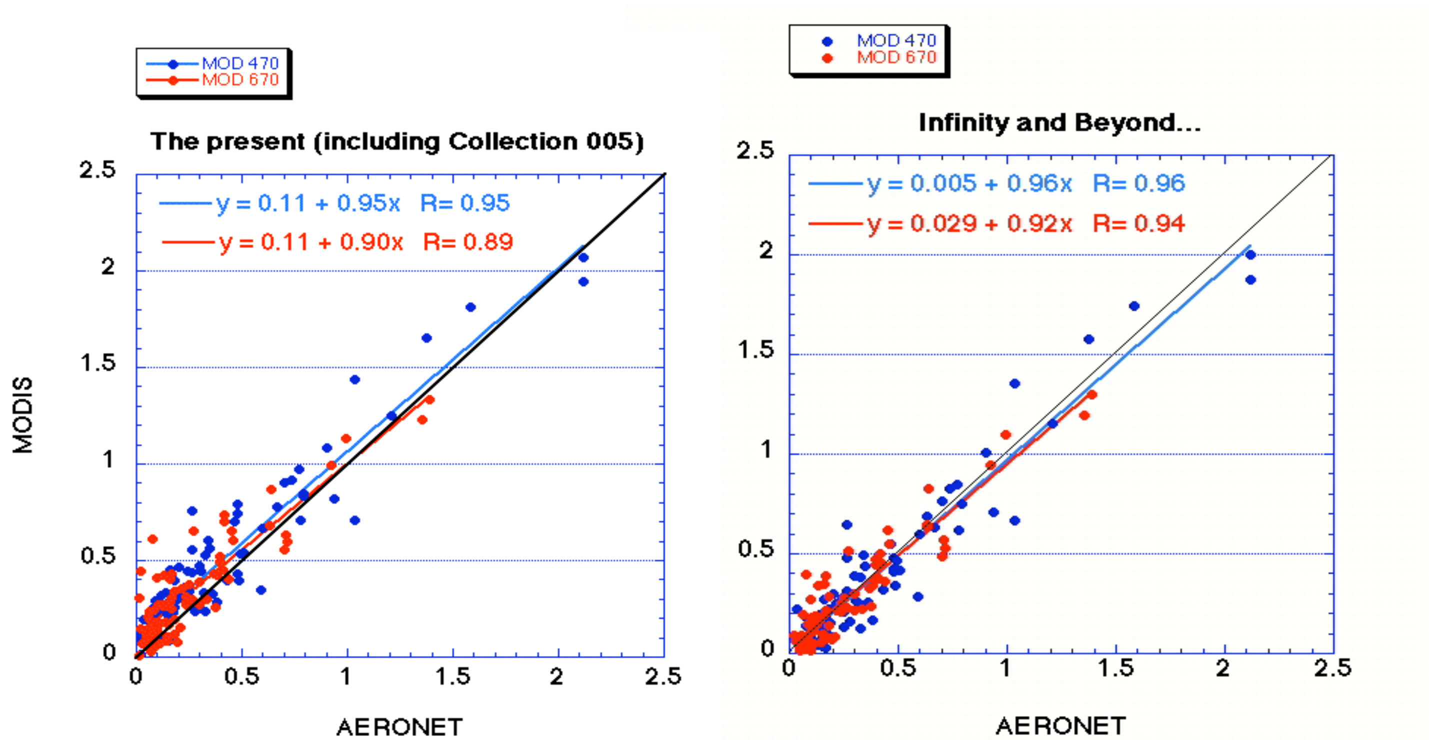


Figure D1. Validation plots of test showing current land aerosol retrieval (left) and proposed revision to land reflectance assumptions (right). Positive offset is reduced from 0.11 to 0.005 in the blue and 0.029 in the red. This proposed change is still underdevelopment and the test seen here may not become the final revision.

D3. Redesign of land inversion structure

In addition to implementing new land surface reflectance assumptions the land algorithm's assumptions and structure have undergone complete re-evalutation. A new land look up table has been created that includes some fine tuning to the original aerosol models. However, the largest change will be in the inversion structure itself. In the current algorithm we make two independent channel inversions and interpolate the value at 550 nm. In the new inversion, we apply a true inversion, much as we do over ocean. The inversion will return an estimate of aerosol optical thickness and an aerosol model.

All channel values will be linked together and the fine mode fraction will also be based on that aerosol model. We expect modest changes to the optical thickness results, but substantially greater information from the fine mode fraction by implementing this structural change.

D4. This cirrus correction

In order to reduce the 10-15% contamination of thin cirrus in our products we are investigating a correction method that will use the cirrus reflectance calculated using the 1.38 μm channel.

E. Publications

Below we list a selected sample of publications beginning in 2002 of specific interest to the MODIS aerosol algorithm or products. Included are publications that our group has either authored or co-authored, as well as several selected publications that have used the MODIS data independently.

2002

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Levy, R. C., Remer, L. A., Tanré, D., Kaufman, Y. J., Ichoku, C., Holben, B. N., Livingston, J. M., Russell, P. B. and Maring, H.: Evaluation of the MODIS retrievals of dust aerosol over the ocean during PRIDE., J. Geophys. Res., 108, 10.1029/2002JD002460, 2003.

Li, R.-R., Kaufman, Y. J., Gao, B.-C. and Davis, C. O.: Remote sensing of suspended sediments and shallow coastal waters., IEEE TGARS, 41, 559-566, 2003.

Wang, J. and Christopher, S. A.: Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implications for air quality studies., Geophys. Res. Lett., 30, 2095, doi:2010.1029/2003GL018174, 2003.

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Chin, M., Chu, D., Levy, R., Remer, L., Kaufman, Y., Holben, B., Eck, T., Ginoux, P. and Gao, Q.: Aerosol distribution in the northern hemisphere during ACE-Asia: Results from global model, satellite observations and sunphotometer measurements., J. Geophys. Res., 109, D23S90, doi:10.1029/2004JD004829, 2004.

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